Teaching Physics Using PhET Simulations

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PhET Interactive Simulations (sims) are now being widely used in teaching physics and chemistry. Sims can be used in many different educational settings, including lecture, individual or small group inquiry activities, homework, and lab. Here we will highlight a few ways to use them in teaching, based on our research[1] and experiences using them in high school and college classes. On our website we have a more complete guide to using PhET sims in the classroom: phet.colorado.edu/teacher_ideas/classroom-use.php.

Sims can be highly effective learning tools; however, even the best sims are not automatically successful. They are tools that can enhance a well-designed curriculum and the efforts of a good teacher, but they cannot replace them. They must still be part of an overall instructional design and rely on the timely guidance of a teacher.

The basic strategies for using sims effectively match those for all effective teaching. These strategies are discussed in our guidelines for creating inquiry-based activities (phet.colorado.edu/teacher_ideas/contribution-guidelines.php). Briefly, they include:

1) define specific learning goals;
2) encourage students to use sense-making and reasoning;
3) connect with and build on students' prior knowledge and understanding (including addressing possible misconceptions);
4) connect to and make sense of real-world experiences;
5) encourage productive collaborative activities;
6) do not overly constrain student exploration;
7) require reasoning/sense-making in words and diagrams (i.e. multiple representations); and
8) help students monitor their understanding.

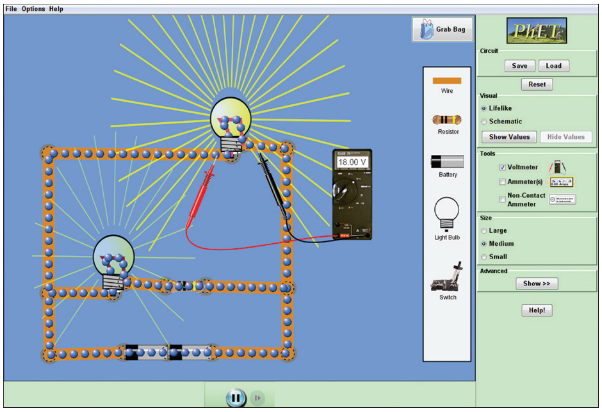

Fig. 1. ***Circuit Construction Kit*****. Students can build any circuit they want. Electrons are shown moving in the wires, and the light bulb lights once a complete circuit is created.**

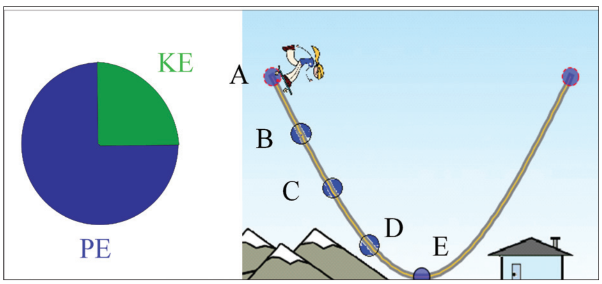

Fig. 2. Concept test. The pie graph shows the energy of the skater at a later time, where could she be on the track?

Ways to use PhET sims in teaching

PhET sims can help: introduce a new topic, build concepts or skills, reinforce ideas, and provide final review and reflection. Sims are unique in the way they can blur the boundaries between lecture, homework, in-class activities, and laboratory, because one sim can be used in similar ways in all of these. They also can provide a common visualization between students and teacher that can facilitate all communication and instruction.

Lecture

Sims can be used as simple animated illustrations, in concept tests,[2] or in the form of interactive classroom demonstrations. As an animated illustration, the sim shows the process and can be slowed or sped up depending on the concept being shown. The invisible (photons, electrons, fields, etc.) can be made visible; and multiple representations (e.g., motion of the skater and different graphs) can be clearly linked. With concept tests (Fig. 2), the teacher poses a question.[3] Typically, the students discuss the question with their neighbors and vote on the answer.

Perhaps the most effective way to use sims in lecture is to begin with the teacher posing a scenario and asking students to write down their predictions.[4] For example, students can be asked to predict what the kinetic and total energy graphs will look like as a function of time as the skater moves on the track in *Energy Skate Park* (Fig. 2). After students have written down individual predictions, they talk with their neighbors to come up with a final prediction for their group. The teacher asks to hear predictions from the class and then runs the sim. After students see what the sim does, they write down what did happen and how it was different from their predictions. Finally, there is a whole class discussion about what they saw, and why it makes sense based on physics ideas.

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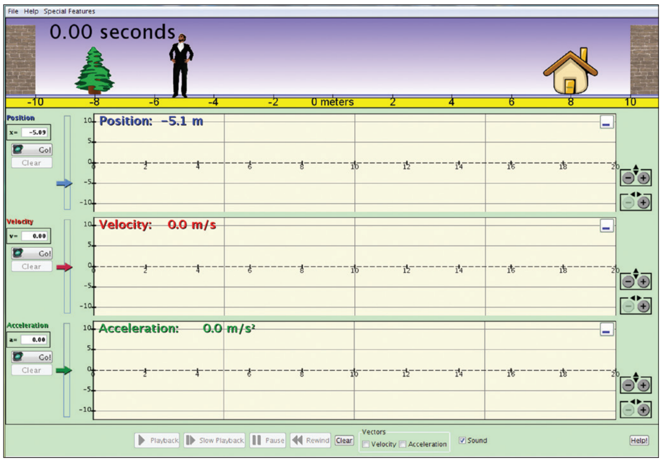

Fig. 3. Inquiry activity for H.S. physics class using *Moving Man.* Sketch what you think the graphs will look like for this story that Jill told:
"Bobby was talking to me on his cell phone standing by the tree. The phone signal was poor, so he walked toward his house trying to get a better signal and then stood still so we could talk."
A. Explain why each part of your graph makes sense.
B. Test your ideas using the sim.

In our experience, the use of simulations in lecture in almost any form leads to a large number of spontaneous student questions. Students will often pose "what if?" questions, essentially new experiments they would like the teacher to perform with the sim so that they can see the results.

While sims offer many of the same benefits as doing demonstrations using real equipment, the sims also have several additional advantages:

1) they can be used in classrooms where the real equipment is either not available or impractical to set up;
2) they can be used to do "experiments" that are impossible to do otherwise (e.g., sim shows immediate response to adjusting the amount of greenhouse gas in the atmosphere or the resistance of a bulb in a circuit);
3) it is easy to change variables in response to student questions that would be difficult or impossible to change with real apparatus;
4) they can show the invisible and explicitly connect multiple representations; and finally,
5) the students can run the sim on their own computer at home to repeat or extend the experiments from class to clarify and strengthen their understanding.

Group activities

When possible, it is even more effective to have the students work in pairs with their own computer and manipulate the sim themselves. The sims are carefully designed and tested to be easy to use and engaging for students. Classroom activities with sims can include a wide range of activity types.[5,6] The goal of all of these types is to ask questions that will encourage students to explore the behavior of the sim, reason through their ideas, and develop corresponding mental models. One format we have often used is to give the students a sequence of challenging questions (often using a "predict-test-confirm or adjust thinking" approach) related to the sim, often with some real-world connection component (Fig. 3).[7]

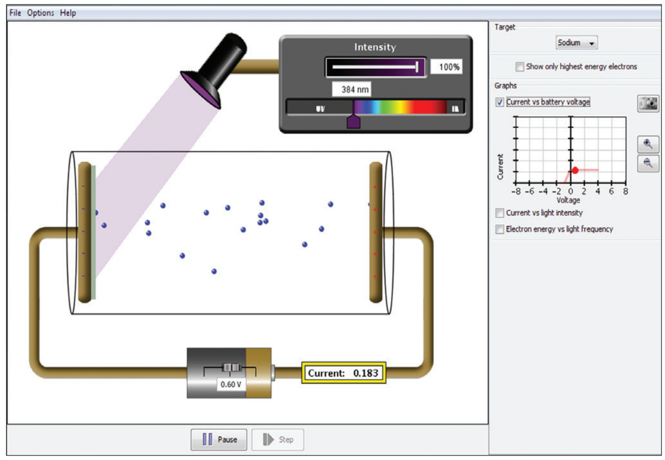

Fig. 4. The *Photoelectric Effect* sim allows light of different intensities and colors to be shown on various materials. Electrons are emitted with different energies. All the parameters of the original experiment can be adjusted.

Homework activities

Frequently, we assign sim-based homework after using the sims in lecture or with an in-class activity. However, sim-based homework questions can also provide introductory exploration of a topic before students have seen it in class.[8] The simulations are unique because their design allows homework assignments to successfully use a guided inquiry approach without the presence of a teacher.[9] This built-in support also allows teachers to include homework questions that ask the students to extend their learning beyond what is possible in a standard homework problem by having them explain phenomena related to, but different from, what they have seen in class or in the textbook (e.g., exploring ideas about gases and pressure, and extending them to the contexts of suction cups, high altitude breathlessness, and balloons).[10]

Laboratory activities

Sim "labs" enable exploration that would not be practical with real equipment. For example, with *Energy Skate Park*, students explore energy conservation with multiple different variables (shape of the track, starting height and speed of the skater, mass of the skater, and friction). Students can quickly repeat experiments and rapidly explore the effect of many different parameters. They can even compare skateboarding on the Moon or on Jupiter with skateboarding on Earth. Another example of lab sim activities that we have found useful are quantum labs where students can reproduce classic experiments, e.g. with the *Photoelectric Effect* sim (Fig. 4)[11,12] and the *Stern-Gerlach* sim. Sims can also be used as a supplement to hands-on equipment laboratories, as pre-lab assignments, part of the lab itself, or as a follow-up assignment. Finally, the sims allow teachers to assign lab-type activities as homework.

PhET activities database

The PhET website includes a "Teacher Ideas & Activities" database (phet.colorado.edu/teacher_ideas/browse.php) that

includes activities written by teachers who use PhET sims with their students. All teachers are encouraged to contribute ideas on how they have used PhET sims. This database can be searched by sim, type of activity, grade level, and keywords. Not all of these activities are written as guided inquiry activities, but those that we have examined, and we believe fit the guided inquiry guidelines, have been marked with a gold star.

Unique characteristics of sims

There are some unique characteristics of sims that can be capitalized on when designing activities. The most significant differences from other media are that: a) sims are quite engaging; b) expert-like models are made more explicit; c) addressing common misconceptions is often built into the design (e.g., showing current as moving electron spheres to directly counter the model that current is "used up"); and d) considerable guidance and feedback is built into the sim (only specific parameters can be adjusted and students see an immediate response to changes). This implicit guidance can reduce the time students spend "getting stuck" trying to figure things out. Also, it means the students can go much deeper into the material without explicit guidance or feedback from the teacher. However, the amount of guidance on the science provided by the sim and the amount the teacher needs to provide depends on the particular sim and the background of the students. Sims such as *Balloons and Static Electricity* or *Faraday's Electromagnetic Lab* require very little guidance, while *Simplified MRI* requires considerable guidance.

These unique characteristics of sims make them a unique learning environment. Students will explore sims more productively on their own than they would textbooks or most lab experiments. We have found that it is important to not "over-guide" sim use. With guidance that is too explicit and structured, students actually explore and learn less.[13] Because the amount of guidance needed with a PhET sim is less than with traditional materials, we suggest first trying to use the sim with your students with less guidance than you normally would. Then add some guidance if you see it is necessary. The key is to engage the students in productive self-driven exploration.

A particularly important aspect of learning physics or chemistry is to develop mental models of the science. A sim can represent expert models more explicitly than other materials, by showing things such as explicit representations of electrons, vectors, or electric fields (Fig. 1). However, there is still a great deal of thinking required for the students to make sense of the sim and to develop their own correct mental model. In fact, one way to use sims in class is to use them as an example of a scientific model. After a sim is used, the instructor can talk about how it is a model of the natural phenomena but not an exact replica and what it means to have a model.

As with any learning tool, PhET sims need to be carefully integrated into the curriculum with appropriate activities created around them. With this approach, PhET sims provide a unique tool that makes learning more fun and more effective.

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